High-Resolution Structure of Bioluminescence Potential in the Nearshore Coastal Waters: Processes And Prediction

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LONG-TERM GOALS

My long-term goal is to advance our understanding of the ecology of bioluminescent organisms and the mechanisms governing the temporal and spatial variability of bioluminescence in the coastal ocean. With improvements in technology, finer-scale resolution and concurrent physical, chemical and biological data, I will examine the predictability of bioluminescence events in the nearshore coastal ocean.

OBJECTIVES

I propose to integrate a bioluminescence autonomous underwater vehicle (AUV) capability into the existing observation networks in the coastal waters of both coasts of North America. Obtaining fine-scale bioluminescence data in conjunction with a suite of ongoing physical, chemical and biological measurements will significantly advance our understanding of the processes governing the temporal and spatial variability of bioluminescence in the coastal ocean. This, combined with the forecasting objectives of the observational networks, will also provide a mechanism and framework for predicting bioluminescence potential in the coastal ocean. In addition to providing the basic science and ecology of bioluminescence, the AUV will provide important performance data that will help to fully characterize the instrument system for the Navy.

APPROACH

In order to address the objectives, above the following approaches were used. 1) Modify, design and fabricate bioluminescence bathyphotometer (BBP) for integration into a new generation of the Remote Environmental Measuring UnitS (REMUS) vehicle. Modify, design and fabricate AUV for measurements of nearshore coastal bioluminescence. 2) Deploy the AUV within the Long-Term Ecosystem Observatory (LEO-15) network grid off the coast of New Jeresy during the Coastal Predictive Skills Experiments (June-August 2001-2003). In conjunction with the ongoing physical, chemical and biological measurements at LEO-15, identify the significant bioluminescent organisms and define the physical forcing of these communities during summer upwelling events. Integrate bioluminescence measurements in the data assimilation model being developed at LEO-15 as part of ONR-HyCODE program. 3) Deploy the AUV in the Santa Barbara Channel from SEPTEMBER-MAY (2001-2003). 4) Coordinate deployments with the ongoing physical, chemical and biological

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measurements in the NSF's LTER program to identify the significant bioluminescent organisms and define the environmental forcing of these communities during the episodic Winter and Spring rain events.

Figure 1. Bioluminescence REMUS AUV and nosecone (inset)

WORK COMPLETED

From October 2000 to June 2001, the new bioluminescence detector compatible with the REMUS AUV was designed and fabricated in collaboration with J. Case at UCSB (Figure 1). The new nosecone combines the technology of the third generation bathyphotometer with the REMUS nosecone design to minimize drag with the front section acting as a light baffle, and more importantly to obtain water in the front of the vehicle that has not been previously stimulated. The bathyphotometer nosecone was also made to accommodate a number of other instruments of interest; a Seapoint fluorometer, an Ocean Sensors CTD and a Seapoint optical backscatter sensor. In March 2001, I participated in a REMUS training mission with the ONR's Chemical Sensing in the Marine Environment group at San Clemente Island. Training included general operation, mission planning, and vehicle maintenance on five missions. In July 2001, the nosecone was integrated (electronically, mechanically) with the REMUS vehicle at Woods Hole in collaboration with J. Case (UCSB) and Chris von Alt (WHOI) (Figure 1). Ballast testing and one field test also followed the integration to assess performance. Appropriate changes to the existing REMUS software were also made during this time to accommodate the newly integrated sensors. In July, 2001, the REMUS vehicle with the integrated bioluminescence nosecone was delivered to Rutgers University Marine Field Station (RUMFS). An AUV team was established and 3 initial successful tests of the vehicle took place in daylight in Great Bay off of RUMFS (Figure 1). Two nighttime deployments took place 5 – 6 km off the coast on the 21^{st} and 28^{th} of July, 13km and 12km missions respectively. These were the only two periods at night during the field effort when swells were low and wind waves were less than 1 meter. The vehicle performed well over these two runs (see below). After the field season at LEO-15, the vehicle was returned to WHOI for minor adjustments. In September 2001, as an addition to this program, I participated in the bioluminescence portion of the MOOS Upper-Water-Column Science Experiment (MUSE). Data from this experiment were presented from analysis from the 67 successful

AUV runs, 48 profiling stations with the optics package, and 34 stations were zooplankton-phytoplankton-nutrient sampling were taken as part of a predictability feasibility study. In September 2001 as an ONR's Young Investigator, I became an adjunct faculty member of the Ecology, Evolution and Marine Biology Department at UCSB to formalize collaboration with the NSF Long-Term Ecological Research program ongoing at UCSB.

RESULTS

Results are presented here for the two deployment dates in 2001, July 21 and 28. The AUV deployment on the 21st was part of a larger multiplatform effort coined "Operation Black Moon" (see Moline report for N00014-00-1-0008). As part of this bioluminescence mapping experiment, the LEO-15 network was used to adaptively sample frontal regions within the modeling space off the coast of New Jersey. Orbview-2 satellite imagery was obtained in the morning of the 21st LT, which provided initial information on the distribution of phytoplankton in the area. A distinct front was identified and targeted for this study (see http://marine.rutgers.edu/cool/hycode2/data/jul21/010721.1726.ool.gif). As there had been a dramatic downwelling in the region for the previous 4 days and both temperature and salinity were vertically structured, with fresher cold water onshore. At approximately 20:00h LT, the R/V Caleta was sent out perpendicular to the coast to locate and physically characterize the optical front seen in the satellite imagery. In previous studies, large tidal variation during new/full moons were shown to move the location of fronts 3-4 km within hours, so for the successful deployment of the AUV, it was critical to get near real-time information. The R/V Caleta confirmed the presence of the frontal feature and the biological structure in fluorescence. At 22:00h LT, the AUV was deployed approximately 5km off the coast with a mission to yo-yo 4 times alone the identical transect line perpendicular to the coast and to the frontal feature. The duration for each transect line was approximately 30 minutes, so this sampling strategy allowed a temporal examination of the frontal structure in this area. The time of 22:00h LT was chosen as previous analysis of time-series data indicated that the maximum potential was maintained between 22:00h LT and 02:00h LT (see Moline report for N00014-00-1-0008). For this mission, the AUV traveled 13 km over a period of 1.75 hours. Data from the vehicle again confirmed the physical structure in high resolution and also showed the temporal evolution in the structure with the frontal region moving offshore over the mission deployment. Optical backscatter and fluorescence showed as similar movement in the front and also illustrated the decrease in intensity of the frontal feature as material was dissipated over a greater area. This confirmed previous studies showing the effect of tidal movements on the divergence intensity along frontal boundaries. Bioluminescence showed two maximums along this transect line. The inshore maximum was deep and appears to represent a heterotrophic community tracking the bottom of the fluorescence maximum. In the offshore maximum, the bioluminescence potential was more correlated to the fluorescence signal. The intensity of both maximums did not show the range of variability as in other parameters, however the is some indication that the signal of the offshore maximum may have dissipated in response to the expanding frontal region as a result of the maximum outgoing tides that night (this sampling day was the annual maximum for daily tide height difference, and therefore tidal current strength).

The location of the second mission on the 28th was also motivated by the existence of a frontal feature. The vehicle for this mission was programmed to follow multiple depth contours across the transect line, providing a second sampling approach to a similar feature as measured during the 21st. For this mission, the AUV traveled 12 km over a period of 2 hours. Data show a strong thermocline with an inshore optical front (Figure 2). Phytoplankton biomass was maximal just above the thermocline, fanning out to more depths inshore concurrent with temperature and the increase in the optical signal.

Unlike the 21st, bioluminescence potential was strongly correlated to the fluorescence data with a maximum on the thermocline. There were high bioluminescence signals deeper in the water column that were not correlated to the fluorescence signal and represent the heterotrophic signal. This sampling approach provided an improved resolution of the sample area, however the area of coverage was not as extensive as that on the 21st.

For the MUSE effort in collaboration with Paul Bissett (Florida Environmental), a water tagging approach was developed using cluster analysis to examine nearshore bioluminescence. Although this analysis is in the preliminary stage, initial results were promising. Physical, optical and biological (fluorescence) data were used as input variables for the clustering of water mass types.

Bioluminescence data in the identical time/space (not used in the clustering) for these clusters where than tested for significant differences in their variances (MANOVA). Using data from the two lengthy transects made by the AUV in Monterey Bay, we found the clustering to 1) define water mass types

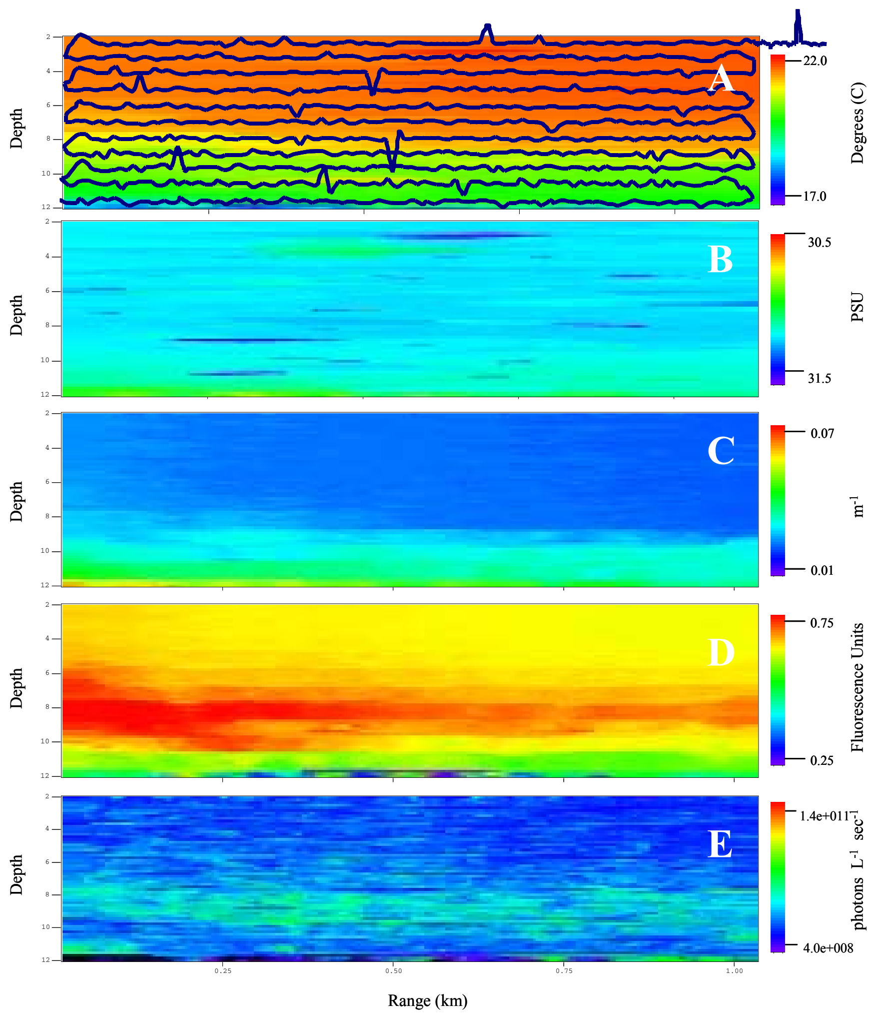

Figure 2. Bioluminescence REMUS results from July 29th, 2001. A) Temperature, B) Salinity, C) Optical backscatter, D) Fluorescence, and E) Bioluminescence Potential. Overlaid on panel A is the vehicle trajectory.

and 2) separate significantly different bioluminescence patterns within the sampling area. The hope was/is to use these clusters to initiate one of the developing models on a larger scale in order to better characterize the sample area and lead to an improved level of predictability with regards to the bioluminescence potential.

IMPACT/APPLICATION

The new bioluminescence AUV is functional and robust in the coastal environment. Sustained use of this platform will increase the vehicle's sampling efficiency and advance the ability to detect fine-scale vertical/horizontal gradients in bioluminescence consistently for durations longer than previous AUV efforts.

TRANSITIONS

This project adds a new high-resolution nighttime bioluminescence capability to existing networks (on both coasts of North America) designed to model and predict the 3-dimensional structure of coastal currents, water density and in-water optical properties on the time scales of hours. Fine-scale vertical bioluminescent measurements coupled with ancillary physical/biological measurements off the coasts of New Jersey and California will improve the ability to predict bioluminescence events and their potential leaving radiance in the nearshore littoral regions of the marine environment. In addition to providing the basic science and ecology of bioluminescence, the AUV will provide important performance data that will help to fully characterize the instrument system for the Navy. This is the first time that this technology has been exclusively operated and maintained by scientists and not by engineers, and illustrates the ease in transitional use this technology.

RELATED PROJECTS

1 – Many ancillary physical and optical measurements were made as part of the ONR-Hyperspectral Coastal Ocean Dynamics (HyCODE) program of which I am presently a PI (ONR- N000149910197). Bioluminescence data from this project will be combined with optical measurements (made by M. Moline and O. Schofield) for the quantification of leaving radiance.

2 – Development of the bioluminescence instrument for the vehicle is assisted through the ongoing collaborations with James Case (UCSB) through my ONR project N00014-00-1-0008.